Study on Breakup of Conical Liquid Sheet under Varying Flow Conditions

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Abstract: An experimental study on the breakup of a conical liquid sheet from a pressure swirl atomizer was conducted by using a Particle Image Velocimetry (PIV) system. The variation of wavelength, wave speed and amplitude of wave versus liquid pressure was obtained. The results indicate that the cone half angle increases with liquid pressure. The stripped half wavelength liquid fragment seems to break into a series of drops immediately and no obvious contraction from liquid fragment to ligament is seen. The recorded images also show that both short and long wavelength waves exist simultaneously, and influence the breakup of the conical liquid sheet. The result of this study is useful for the purpose of developing and verifying the atomization model of spray produced by a pressure swirl atomizer.

Key words: breakup of conical liquid sheet; pressure swirl atomizer; disturbance wave; PIV

不同液压条件下锥形液膜破碎的实验研究. 岳明,徐行,杨茂林,袁辉靖,盛森之. 中国航空学报(英文版),2003, 16(1): 12- 14.

摘　要: 应用 PIV 激光粒子图像测速仪对由离心式压力雾化喷嘴喷出的锥形液膜的破碎进行了实验研究。测得了不同压力下的扰动波波长、波速和振幅。研究结果表明, 液膜半锥角随着液压的增加而增加, 半波长的液膜段剥落后几乎立即破碎成液滴, 看不到明显的液膜段收缩成液丝的过程。由实验拍摄的图像看, 长、短扰动波同时存在, 共同影响液膜的破碎。这些数据可用于发展锥形液膜初始雾化模型。

关键词: 锥形液膜的破碎; 压力雾化喷嘴; 扰动波; PIV 激光粒子测速仪

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Atomization of fuel is a vital important process for spray combustion systems. The pressure swirl atomizers (simplex nozzle) are widely used in air-breathing engine for fuel atomization. Since the mean drop size distribution of the spray and local fuel/air ratios affect combustion efficiency and emissions significantly, a better understanding of the breakup mechanism of the conical liquid sheet would be important to predict and control these parameters, especially, the drop size distribution.

Many methods (experimental or numerical) have been conducted to study the characteristics of the spray by a pressure swirl nozzle. Feikema[1] experimentally investigated the liquid film thickness of a pressure-swirl injector using LPV. The results indicated that the film thickness decreases as the film approaches the injector exit and is approximately 1000μm at the exit. Holtzclaw, *et al.*[2] have studied the internal flow in a simplex fuel atomizer with three different nozzle geometries by Particle Image Velocimetry (PIV) and Arbitrary-Lagrangian-Eulerian method[3,4]. Their results show that the nozzle geometry affects significantly the performance of the nozzle. Sakman and Jog[5] have used the same computational model and cameras to study the liquid sheet emanating from

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the simplex fuel nozzle. The comparisons between the computational predictions and the experimental measurements show very good agreement. But most experimental studies have focused on the fluid flow within the atomizer body or the spray after breaking up. Only limited results of experimental studies on the breakup process of liquid sheet have been published.

In this work, the conical liquid sheet injected from a pressure-swirl nozzle is investigated. The parameters, such as wave-length, wave-amplitude and cone angle of the liquid sheet are measured by Particle Image Velocimetry (PIV).

1 Experiment Apparatus and Method

A large-scale pressure swirl atomizer is used in experiment for better spatial resolution measurements by current diagnostic techniques. A schematic of the atomizer is shown in Fig. 1. In this experiment, water is employed as working liquid.

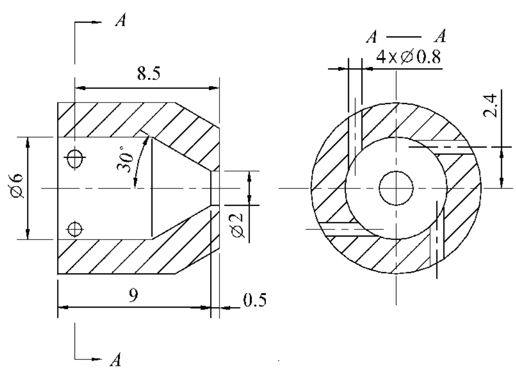

Fig. 1 Sketch of the model pressure swirl atomizer

The experiment set-up and flow schematic are shown in Fig. 2. It consisted of a pressure swirl atomizer, a liquid supply tank and a compressed air tank. The pressure in the air tank is approximately 10MPa. A pressure gauge was mounted above the atomizer to measure the pressure of the liquid. A Particle Image Velocimetry (PIV) system of TSI with two GEMINI YAG lasers was used to record the instantaneous liquid flow near the breakup point of the conical sheet. The laser beam guided through several steering mirrors entered a laser sheet generator and produced a vertical laser sheet of approximately 0.5mm in thickness. Then the sheet passed through the central plan of the conical liquid sheet. A PIVCAM CCD camera was placed in the direction perpendicular to the laser sheet to take images. The fluorophore was added into the liquid to eliminate the effect of background light on the clearness of images.

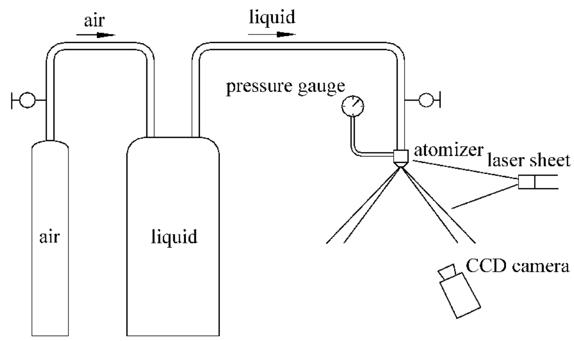

Fig. 2 Set-up and flow schematic of the experiment

The conical liquid sheet produced at liquid pressure ranging from 0.05MPa to 0.75 MPa was measured. The spray angle, amplitude and wavelength of the wave were measured directly from the images respectively. The wave number is calculated from wavelength λ: $k_r = 2\pi/\lambda$. The wave speed was obtained from couple of pulsing images: $c = ds/dt$, where ds is the displacement of same peaks in two images and dt is the pulse separation between two pulses.

2 Result and Discussion

The typical instantaneous images of a conical liquid sheet were taken. These images show that disturbance wave develops along the sheet and the fragment of the sheet sheds from the sheet and breaks up to form droplets. Both short and long wavelength waves can be seen. The images show that the short wavelength wave is three dimensional and the long one is along the liquid sheet. The wavelength increases along the liquid sheet due to the increase of liquid sheet velocity in the meridian plane. Therefore, the wave number decreases along the sheet. The amplitude of wave increases along the liquid sheet. The thickness of sheet decreases along the sheet because of the dispersion of the sheet. The variation of the wavelength, amplitude of the wave and the wave speed at the breakup point versus liquid pressure is shown in Fig. 3.

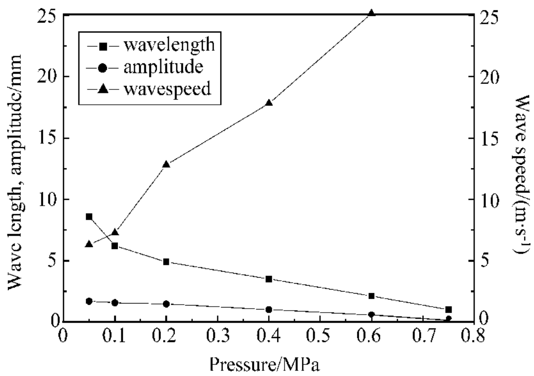

Fig. 3 Wavelength, amplitude and wave speed of disturbance wave at breakup point *vs* liquid pressure

The images also show that the breakup of liquid sheet always takes place at the wave crest in the outer side of the sheet. It is because that at this position, the thickness of the sheet is less than at other positions. When the half wavelength liquid fragment stripped from the sheet, it breaks into a series of droplets simultaneously and no obvious contraction of the liquid fragment to ligament is observed. The thickness of the liquid sheet only decreases slightly as the liquid pressure increases. It means that the disturbance wave has more influence on the breakup of the liquid sheet than the film thickness.

Fig. 4 shows the comparison of the experimental spray angle with the computed result by the empirical expression[6] under different liquid pressures. The spray angle increases along with the raising of liquid pressure because of the surface tension of liquid collapsing the sheet at lower liquid pressure. When the liquid pressure is high enough, the spray angle approaches a constant. But the experimental angles are lower than the empirical predicted result for neglect of the effect of viscosity.

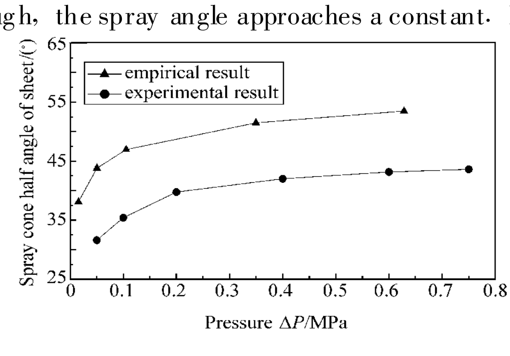

Fig. 4 Spray cone half-angle comparison

3 Conclusions

The characteristics of breakup of a pressure swirl atomizer and the sprays from this breakup have been investigated experimentally by using PIV. The following conclusions can be drawn:

(1) The cone half angle increases along with the raising of liquid pressure and approaches a constant at last.

(2) The disturbance wave has more influence on the breakup of the liquid sheet than the film thickness.

(3) As the liquid pressure increases, both the wavelength and the amplitude of the disturbance wave at the breakup point decrease.

(4) The characteristic parameters at several liquid pressures have been obtained. These parameters are used for developing and verifying the atomization model of spray.

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